Determination of Volume Correction Factors for FAME and FAME / Mineral-diesel blends

Carried out for the Energy Institute by
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1 Introduction

This report presents work done to measure the thermal expansion and compressibility of samples of diesel with added FAMES.

The work was organised through the UK Energy Institute (formerly the Institute of Petroleum) Oil Transportation Measurement Committee, HMC-4, and carried out by H&D Fitzgerald Ltd. The project was managed by the UK Energy Institute. (Paul S. Harrison.)

2 Acknowledgements

2.1 Finance

The following organisations provided funding for the work:

ConocoPhillips
Chevron
Total SA
Shell
US DESC
Energy Institute

2.2 Samples

Samples were provided by:
Shell Global Solutions
Carless Petroleum

2.3 Software

API Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils, May 2004 and Addendum September 2007.
This was used to calculate compressibility factors and convert observed densities to densities at 15°C as per the Petroleum Measurement Tables -

Table 53A-Generalized Crude Oils, Correction of observed density to density at 15°C
Table 53B-Generalized Products, Correction of observed density to density at 15°C
Table 54A-Generalized Crude Oils, Correction of volume to 15°C against density at 15°C
Table 54B-Generalized Products, Correction of volume to 15°C against density at 15°C

3 Summary

Precise measurements of density, temperature and pressure were made on a total of 31 samples, at temperatures from 5 to 80°C, and pressures of 1 to 7 bar.

The samples measured were as follows:
FAME-free winter diesel
FAME-free summer diesel
Pure soya FAME
Pure palm FAME
Pure rape FAME
Pure coconut FAME
Pure tallow FAME
B5, B10, B20, B60 blends of soya, palm and rape FAMES in both winter & summer diesel.

3.1 Preparation of samples for testing

The two samples of straight hydrocarbon diesel – winter and summer, were stored in glass 5 litre containers. No additional protection was regarded as necessary because they have little tendency to absorb water from the atmosphere.

The FAME samples were stored differently because of their rapid uptake of water.
Schott-Duran bottles were adapted to take lids carrying stoppered luer fittings, and FAME / diesel blends were made by using dried air to push the FAME into the sealed bottles.
The density of all liquids was determined by DMA 5000 before mixing in order to obtain target weights for the blends.

A Karl Fischer instrument which had previously been calibrated with standards of a known water content was used to determine the water contents of all FAMES and mineral diesel samples, to ensure compliance with EN 14214. The sample of Tallow FAME was found to exceed the 500ppm limit, so it was dried over Molecular Sieve.

Sample	Water content ppm
Mineral diesel summer	47.3
Mineral diesel winter	47.2
Coconut ME	320
Soya ME	322
Rape ME	429
Palm ME	385
Tallow ME	642
Tallow ME sample dried	430

4 Experimental arrangements

4.1 Equipment and procedure

The work was carried out using an Anton Paar DMA 5000 density meter, controlled by specially written software.
This provided multiple determinations of density whilst changing the temperature to cover the test range from 5 to 80°C.
It had previously been found that some of the FAMES started to crystallise below 20°C, therefore temperature steps were run in the order of 20, 25, 30, 35, 40, 45, 50, 60, 80, 20, 15, 10, 5, 20°C.
The repetition of the 20°C steps allowed a check to be made for any compositional changes, wax deposition, out-gassing, etc., which may have occurred during the cycle.
In addition to working at 1 bar, densities at these temperatures were also determined at pressures of 2, 3, 5 and 7 bar, to allow compressibilities to be calculated. Samples were injected against a simple weighted piston back pressure device which maintained the sample at each of the set pressures throughout the analysis. 20 sets of observations of density, temperature and pressure were recorded at each step.
A total of 70 separate data points were therefore collected for each sample.

4.2 Traceability of temperature

Density cell temperatures were checked every couple of months during the project with either a micro platinum resistance probe or a high stability thermistor. Both devices were themselves calibrated using water triple point and gallium melting point cells, both of which have UKAS ISO 17025 accredited calibration.
The estimated uncertainty in quoted cell temperature is ± 15 mK (k=2). Most of this is due to cell temperature drift between calibrations.

4.3 Traceability of pressure

The pressure sensor was calibrated against a pressure balance with UKAS ISO 17025 accredited calibration.
The estimated uncertainty in quoted cell pressure is ± 30 mbar (k=2).

4.4 Traceability of density

The system was calibrated with 2 liquid density standards which had been calibrated by H&D in their UKAS accredited laboratory. One had a density of 750kgm^{-3} at 20°C, with an uncertainty of ±0.01 kgm^{-3} (k=2); the other a density of 868kgm^{-3} at 20°C, with an uncertainty of ±0.03 kgm^{-3} (k=2), and a viscosity of 8MPa·s at 40°C. Deaerated distilled water of known isotopic ratio was also used as a calibrant, the density being derived from the IAPWS equation with a correction for isotopic deviation from VSMOW.
Calibration was carried out at each temperature and pressure.

The calibration data was then used to generate a calibration surface which gave density as a function of oscillation period, cell damping factor, temperature and pressure.
Analysis of the residuals and uncertainty components for samples with viscosities up to 20 mPa·s suggests that this surface gives absolute densities with an uncertainty of ± 0.08 kgm^{-3} (k=2). For a given sample, the density at any one temperature compared with the density at another temperature has an estimated uncertainty of ± 0.04 kgm^{-3} (k=2).

5 Results

The results are summarised in the tables and graphs which follow.

5.1 The experimentally determined density at 15°C for each sample and blend.

5.2 The three constants for a quadratic equation to predict density at any temperature between 5 and 80°C, together with the residual standard deviation.
The two constants for a linear equation to predict density at any temperature between 5 and 80°C, together with the residuals standard deviation.

5.3 Comparison of the predicted volume at 15°C, assuming a volume of 10000m^3 at 5°C, by four methods:
- Petroleum Measurement Tables 53 and 54
- quadratic fit
- linear fit
- EN14214

Graphs of these results categorised by FAME type.

5.4 Comparison of the predicted volume at 15°C, assuming a volume of 10000m^3 at 25°C, by four methods:
- Petroleum Measurement Tables 53 and 54
- quadratic fit
- linear fit
- EN 14214

5.5 Compressibility in $kgm^{-3}bar^{-1}$ at 15°C.
Graphs comparing these results with the PM tables, categorised by FAME type.

5.6 Linear expansivity coefficients.

5.1	FAME mass %	FAME volume %	experimental density 15°C
Soya in Summer derv			
B100	100.00	100.00	885.65
B60	61.24	60.00	867.40
B20	20.88	20.03	849.34
B10	10.48	10.00	845.03
B5	5.25	5.00	842.85
B0	0.00	0.00	840.69
Soya in winter derv			
B100	100.00	100.00	885.65
B60	61.73	60.03	860.89
B20	20.85	19.70	836.54
B10	10.47	9.82	830.68
B5	5.25	4.91	827.79
B0	0.00	0.00	824.93
Palm in summer derv			
B100	100.00	100.00	875.82
B60	60.98	60.00	861.61
B20	20.55	19.89	847.64
B10	10.36	9.99	844.22
B5	5.19	5.00	842.50
B0	0.00	0.00	840.69
Palm in winter derv			
B100	100.00	100.00	875.82
B60	61.36	59.93	855.16
B20	17.39	19.98	836.19
B10	10.54	9.99	829.87
B5	5.28	4.99	827.37
B0	0.00	0.00	824.93

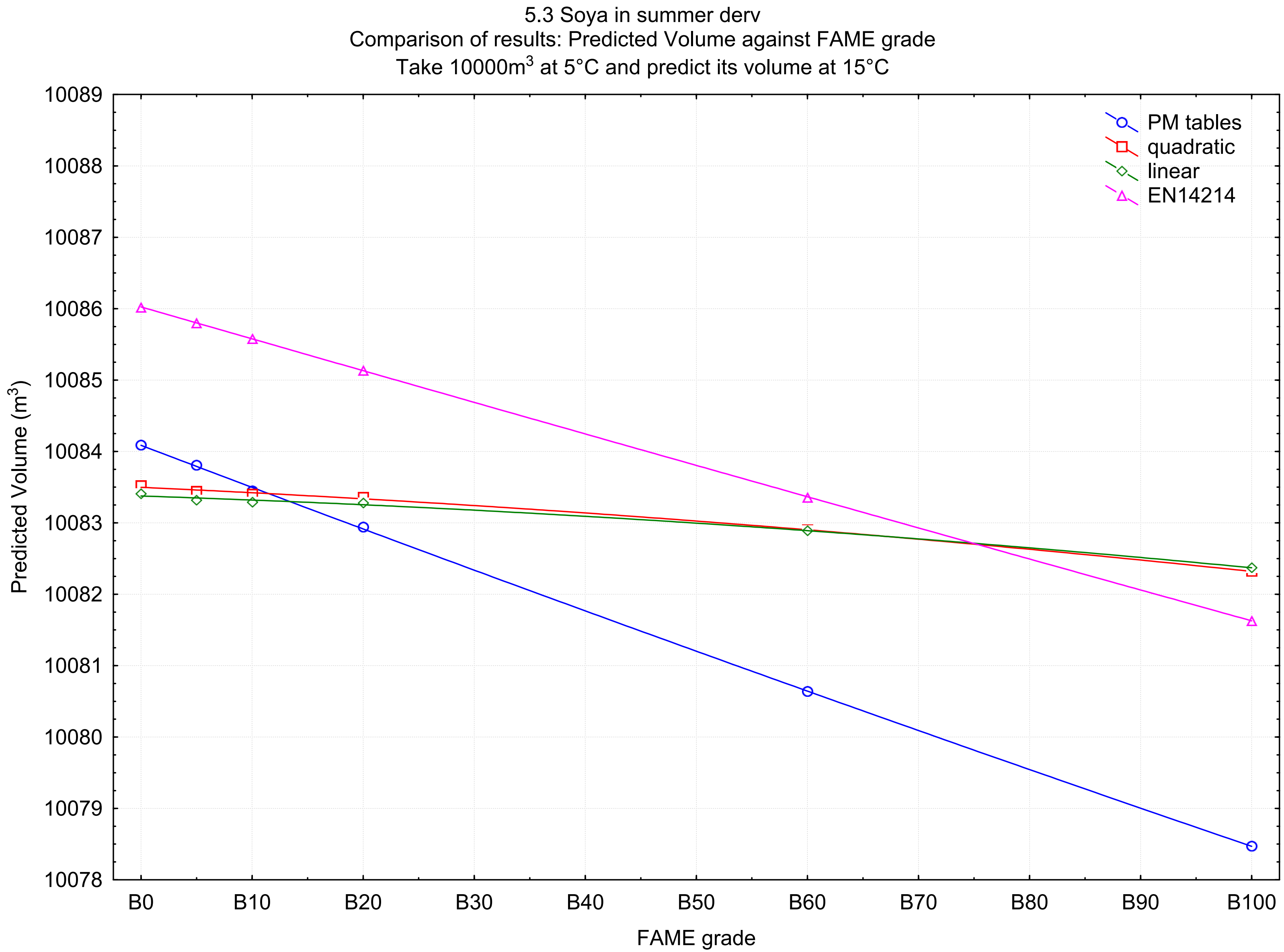
5.1	FAME mass %	FAME volume %	experimental density 15°C
Rape in summer derv			
B100	100.00	100.00	883.58
B60	61.16	59.97	866.19
B20	20.72	19.92	849.00
B10	10.44	9.98	844.84
B5	5.24	5.00	842.85
B0	0.00	0.00	840.69
Rape in winter derv			
B100	100.00	100.00	883.58
B60	61.64	60.00	859.84
B20	21.11	19.98	836.38
B10	10.60	9.96	830.60
B5	5.34	5.00	827.79
B0	0.00	0.00	824.93
Coconut			
B100	100.00	100.00	874.21
Tallow			
B100	100.00	100.00	875.87

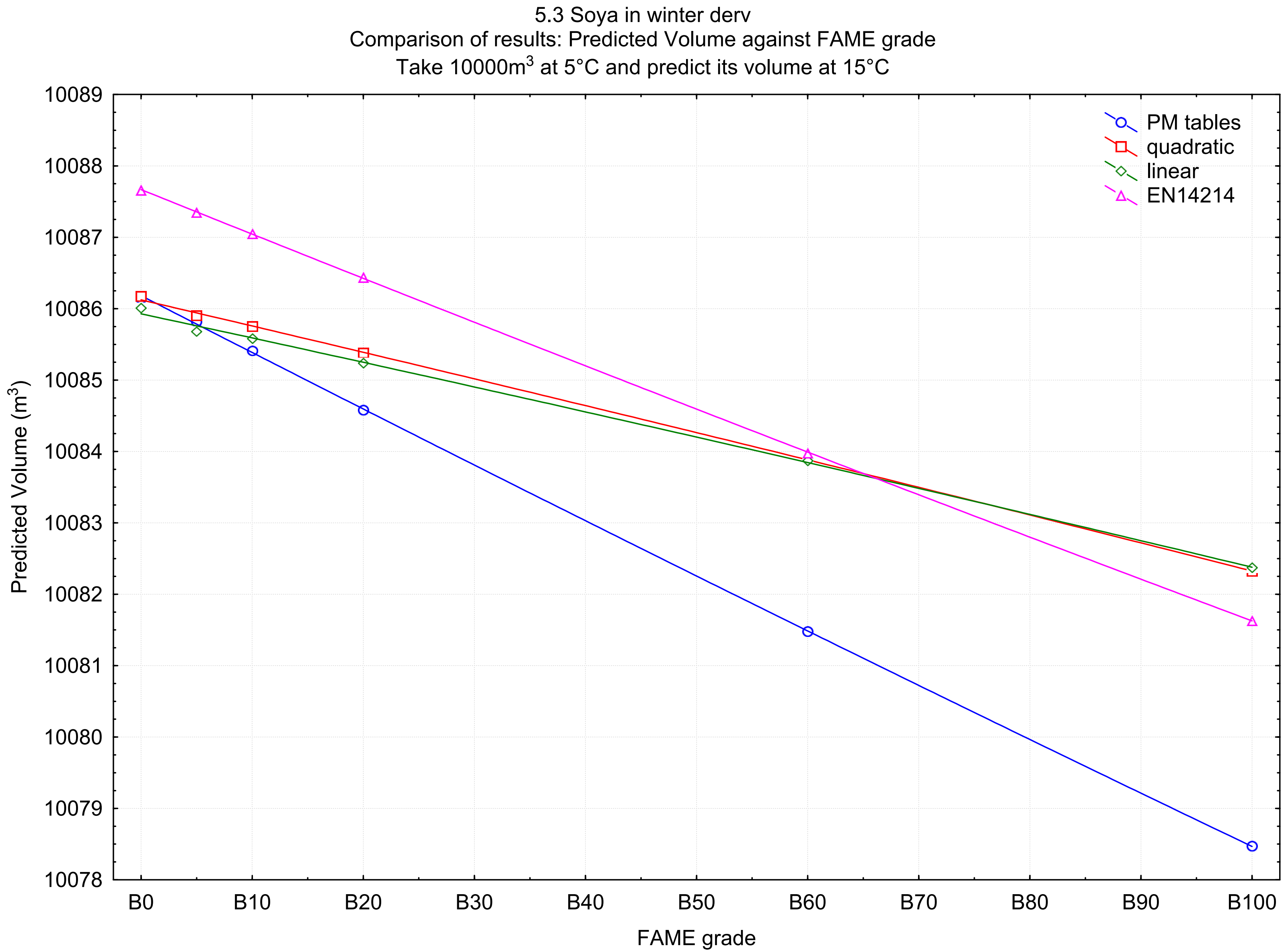
5.2	density 15°C	Expansivity 5-80°C quadratic.				Expansivity 5-80°C linear		
		aq	bq	cq	residual s.d. kg/m^3	al	bl	residual s.d. kg/m^3
Soya in Summer derv								
B100	885.65	896.5841	-0.7296	2.5430E-05	0.016	896.5544	-0.7275	0.021
B60	867.40	878.1820	-0.7190	-4.0530E-06	0.017	878.1868	-0.7193	0.016
B20	849.34	859.9572	-0.7073	-3.7301E-05	0.016	860.0008	-0.7103	0.026
B10	845.03	855.5949	-0.7037	-5.1369E-05	0.013	855.6549	-0.7079	0.032
B5	842.85	853.3936	-0.7022	-5.4832E-05	0.017	853.4576	-0.7066	0.034
B0	840.69	851.2182	-0.7011	-5.1822E-05	0.023	851.2787	-0.7053	0.036
Soya in winter derv								
B100	885.65	896.5841	-0.7296	2.5430E-05	0.016	896.5544	-0.7275	0.021
B60	860.89	871.7208	-0.7220	-1.3421E-05	0.017	871.7365	-0.7231	0.017
B20	836.54	847.2530	-0.7128	-7.1213E-05	0.016	847.3361	-0.7186	0.042
B10	830.68	841.3564	-0.7106	-8.5341E-05	0.013	841.4561	-0.7176	0.049
B5	827.79	838.4507	-0.7092	-9.4626E-05	0.015	838.5613	-0.7168	0.054
B0	824.93	835.5833	-0.7090	-9.0695E-05	0.015	835.6885	-0.7165	0.053
Palm in summer derv								
B100	875.82	886.8159	-0.7335	1.7311E-05	0.012	886.7854	-0.7319	0.014
B60	861.61	872.4289	-0.7212	-4.5720E-06	0.017	872.4342	-0.7215	0.016
B20	847.64	858.2618	-0.7073	-4.3549E-05	0.019	858.3126	-0.7108	0.030
B10	844.22	854.7965	-0.7046	-4.4613E-05	0.018	854.8486	-0.7082	0.030
B5	842.50	853.0532	-0.7027	-5.0179E-05	0.022	853.1118	-0.7067	0.034
B0	840.69	851.2182	-0.7011	-5.1822E-05	0.023	851.2787	-0.7053	0.036
Palm in winter derv								
B100	875.82	886.8159	-0.7335	1.7311E-05	0.012	886.7854	-0.7319	0.014
B60	855.16	866.0265	-0.7243	-1.3136E-05	0.028	866.0421	-0.7254	0.027
B20	836.19	846.8456	-0.7082	-1.5266E-04	0.030	847.0239	-0.7205	0.088
B10	829.87	840.5431	-0.7105	-8.8709E-05	0.015	840.6467	-0.7177	0.028
B5	827.37	838.0311	-0.7095	-9.3089E-05	0.016	838.1398	-0.7171	0.053
B0	824.93	835.5833	-0.7090	-9.0695E-05	0.015	835.6885	-0.7165	0.053

5.2	density 15°C	Expansivity 5-80°C quadratic.				Expansivity 5-80°C linear		
		aq	bq	cq	residual s.d. kg/m^3	al	bl	residual s.d. kg/m^3
Rape in summer derv								
B100	883.58	894.4590	-0.7256	1.9235E-05	0.013	894.4366	-0.7241	0.017
B60	866.19	876.9453	-0.7167	-4.7353E-06	0.019	876.9509	-0.7171	0.018
B20	849.00	859.6043	-0.7066	-3.5411E-05	0.018	859.6456	-0.7095	0.026
B10	844.84	855.4147	-0.7040	-4.4902E-05	0.019	855.4671	-0.7076	0.030
B5	842.85	853.3970	-0.7027	-4.9506E-05	0.019	853.4549	-0.7067	0.032
B0	840.69	851.2182	-0.7011	-5.1822E-05	0.023	851.2787	-0.7053	0.036
Rape in winter derv								
B100	883.58	894.4590	-0.7256	1.9235E-05	0.013	894.4366	-0.7241	0.017
B60	859.84	870.6393	-0.7201	-8.9876E-06	0.018	870.6498	-0.7208	0.018
B20	836.38	847.0802	-0.7127	-6.5095E-05	0.018	847.1563	-0.7179	0.039
B10	830.60	841.2746	-0.7105	-8.3059E-05	0.016	841.3716	-0.7172	0.048
B5	827.79	838.4462	-0.7093	-9.2090E-05	0.016	838.5542	-0.7168	0.053
B0	824.93	835.5833	-0.7090	-9.0695E-05	0.015	835.6885	-0.7165	0.053
Coconut								
B100	874.21	885.8568	-0.7760	-1.9881E-05	0.020	885.8800	-0.7776	0.022
Tallow								
B100	875.87	886.8326	-0.7310	2.0595E-05	0.015	886.7962	-0.7291	0.017

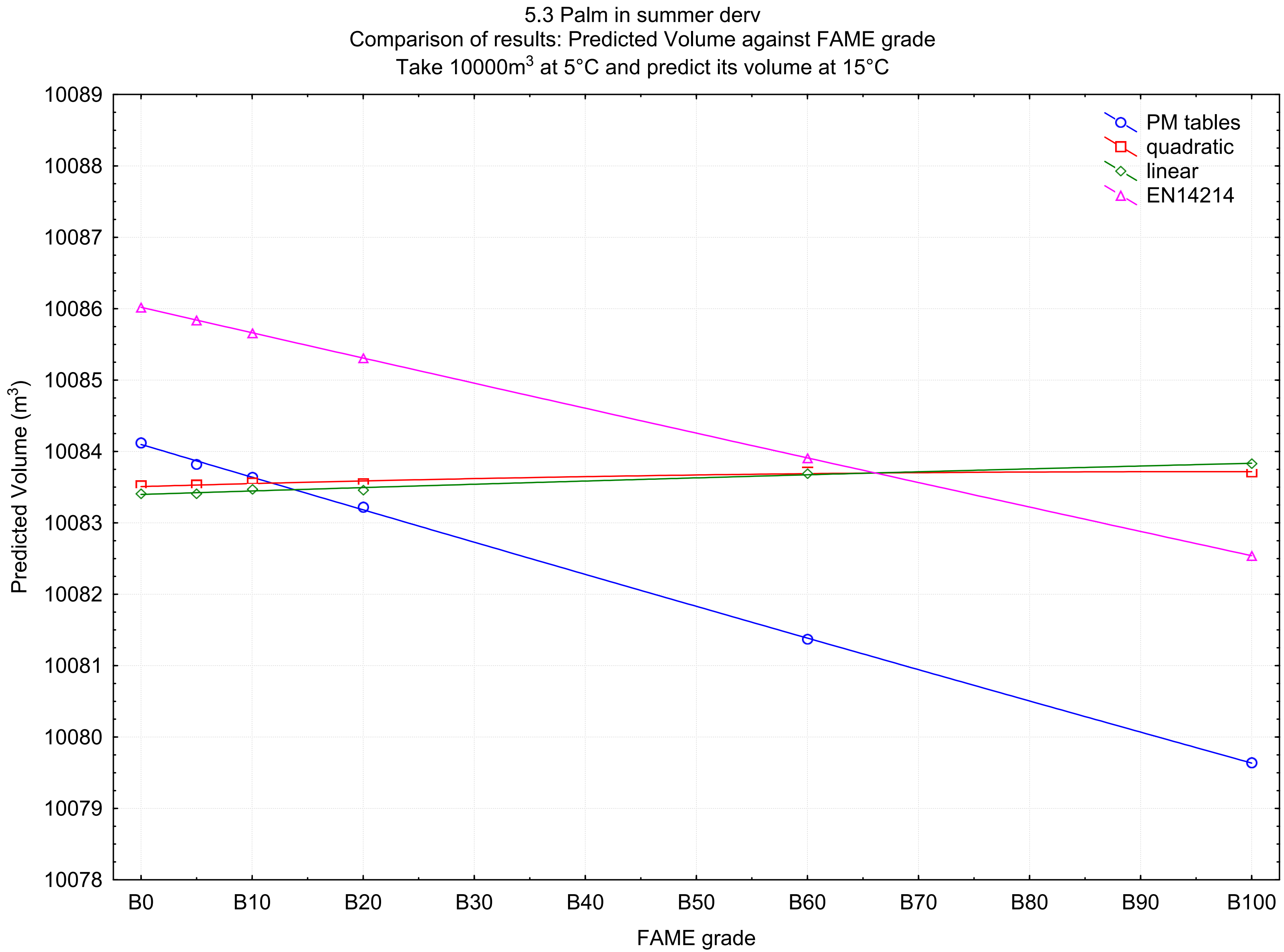
Take 10000 m³ at 5°C and predict its volume at 15°C						
5.3	experimental density 5°C	PM Tables density 15°C	Volume predicted by PM Tables	Volume predicted from lab data quadratic fit	Volume predicted from lab data linear fit	Volume predicted using EN14214
Soya in Summer derv						
B100	892.94	885.98	10078.47	10082.32	10082.37	10081.63
B60	874.59	867.59	10080.64	10082.90	10082.89	10083.36
B20	856.42	849.37	10082.94	10083.36	10083.28	10085.14
B10	852.08	845.02	10083.45	10083.40	10083.29	10085.58
B5	849.88	842.82	10083.81	10083.44	10083.32	10085.80
B0	847.71	840.64	10084.09	10083.52	10083.41	10086.02
Soya in winter derv						
B100	892.94	885.98	10078.47	10082.32	10082.37	10081.63
B60	868.11	861.09	10081.48	10083.90	10083.87	10083.98
B20	843.69	836.61	10084.58	10085.38	10085.24	10086.44
B10	837.80	830.71	10085.41	10085.75	10085.58	10087.05
B5	834.90	827.80	10085.82	10085.90	10085.68	10087.35
B0	832.04	824.93	10086.14	10086.17	10086.01	10087.66
Palm in summer derv						
B100	883.15	876.17	10079.64	10083.71	10083.83	10082.54
B60	868.82	861.81	10081.37	10083.71	10083.69	10083.91
B20	854.72	847.67	10083.22	10083.55	10083.46	10085.31
B10	851.27	844.21	10083.64	10083.56	10083.47	10085.66
B5	849.54	842.48	10083.82	10083.53	10083.41	10085.84
B0	847.71	840.64	10084.12	10083.52	10083.41	10086.02
Palm in winter derv						
B100	883.15	876.17	10079.64	10083.71	10083.83	10082.54
B60	862.40	855.37	10082.24	10084.73	10084.70	10084.54
B20	843.30	836.22	10084.68	10085.06	10084.72	10086.48
B10	836.99	829.89	10085.49	10085.83	10085.64	10087.13
B5	834.48	827.38	10085.87	10085.98	10085.79	10087.40
B0	832.04	824.93	10086.14	10086.17	10086.01	10087.66

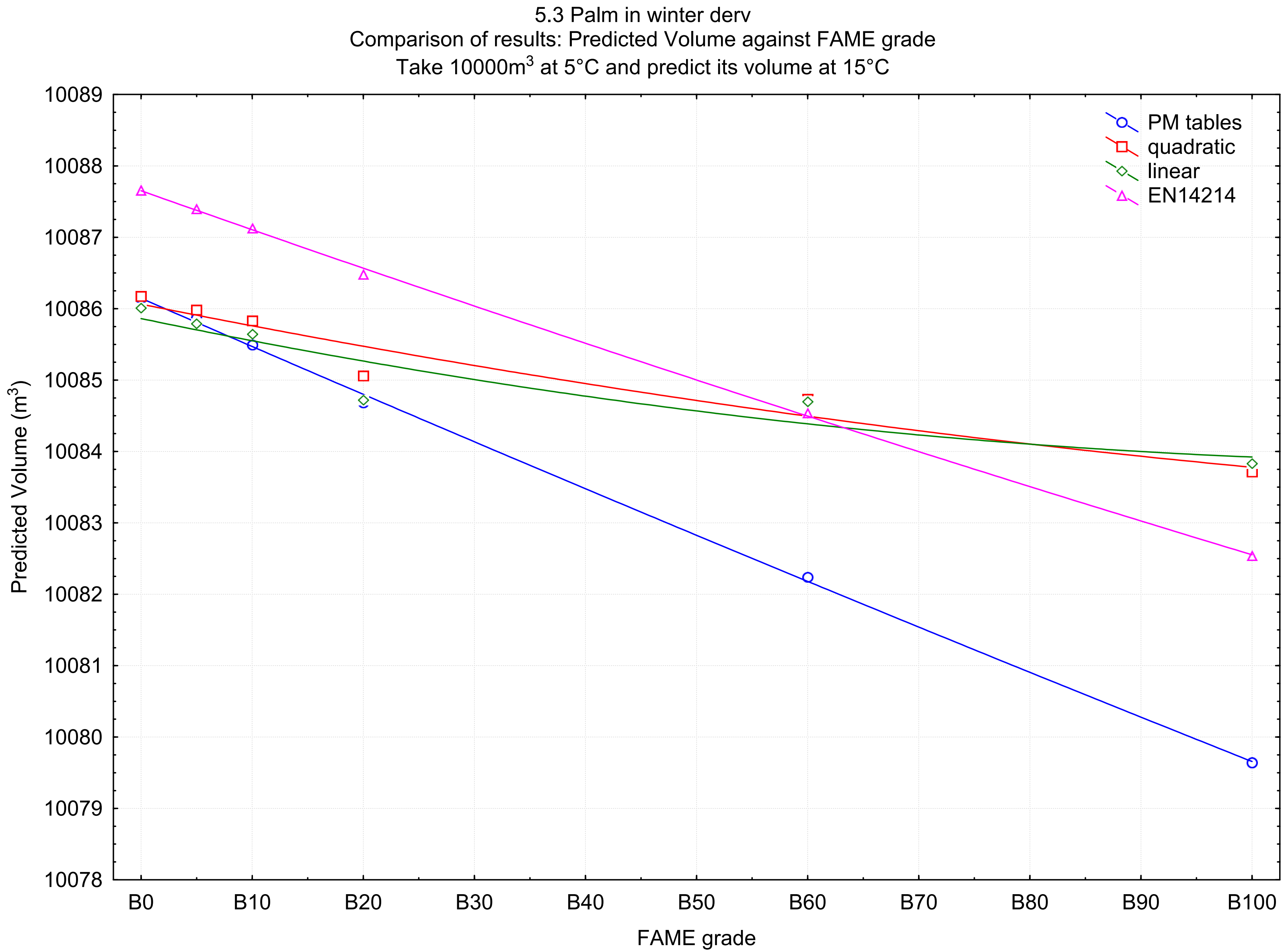
Take 10000 m^3 at 5°C and predict its volume at 15°C						
5.3	experimental density 5°C	PM Tables density 15°C	Volume predicted by PM Tables	Volume predicted from lab data quadratic fit	Volume predicted from lab data linear fit	Volume predicted using EN14214
Rape in summer derv						
B100	890.83	883.87	10078.77	10082.08	10082.13	10081.82
B60	873.36	866.36	10080.85	10082.75	10082.74	10083.47
B20	856.07	849.02	10083.00	10083.31	10083.24	10085.18
B10	851.89	844.83	10083.57	10083.44	10083.33	10085.60
B5	849.88	842.82	10083.82	10083.49	10083.38	10085.80
B0	847.71	840.64	10084.12	10083.52	10083.41	10086.02
Rape in winter derv						
B100	890.83	883.87	10078.77	10082.08	10082.13	10081.82
B60	867.04	860.02	10081.59	10083.77	10083.75	10084.09
B20	843.52	836.44	10084.57	10085.37	10085.21	10086.45
B10	837.72	830.63	10085.41	10085.74	10085.56	10087.06
B5	834.90	827.80	10085.76	10085.91	10085.71	10087.35
B0	832.04	824.93	10086.14	10086.17	10086.01	10087.66
Coconut						
B100	881.98	875.00	10079.75	10088.81	10088.77	10082.65
Tallow						
B100	883.18	876.20	10079.63	10083.41	10083.56	10082.54

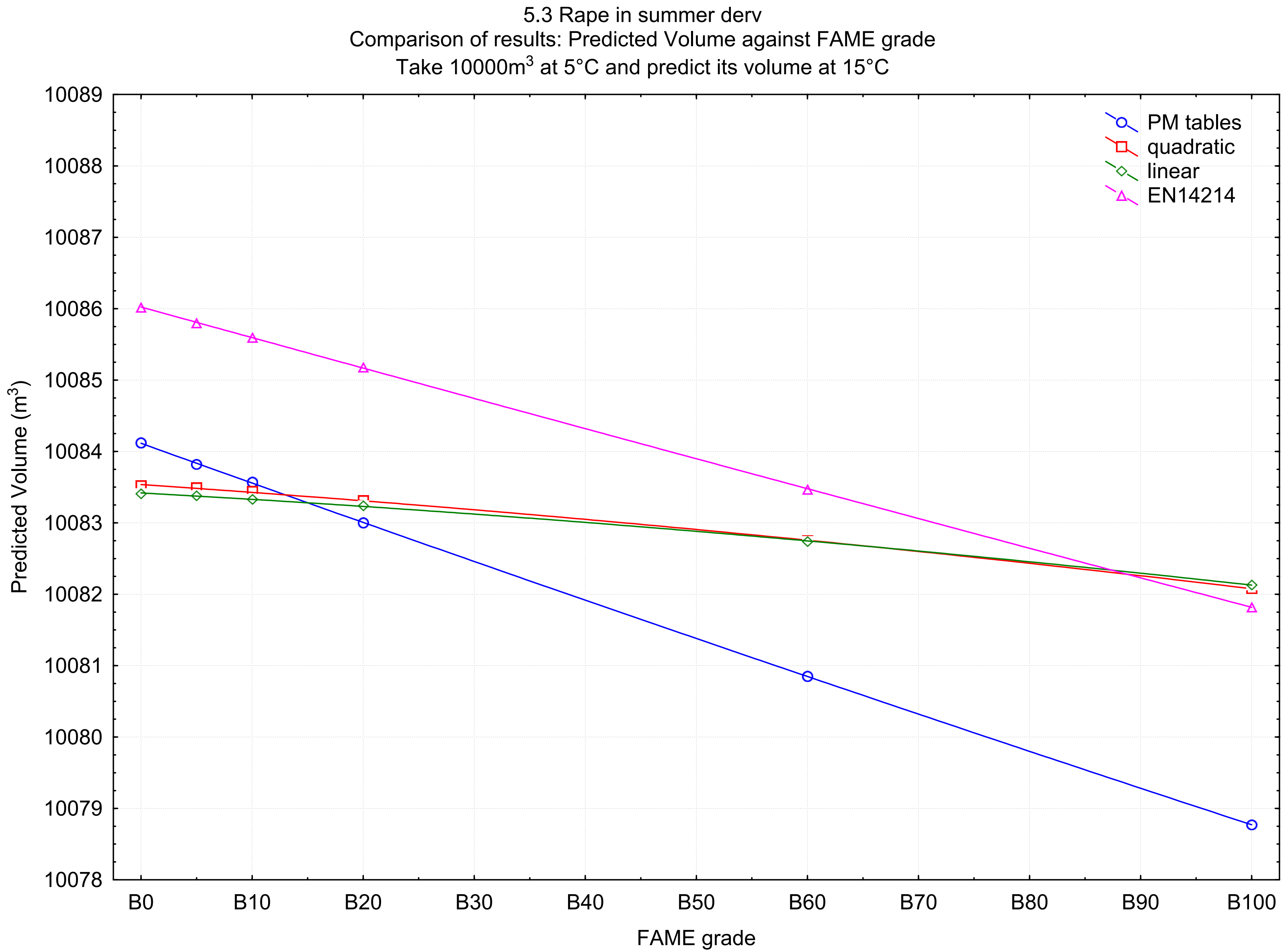

5.3 Soya in summer derv
Comparison of results: Predicted Volume against FAME grade
Take 10000m3 at 5°C and predict its volume at 15°C
Predicted Volume (m3)
FAME grade
10078
10079
10080
10081
10082
10083
10084
10085
10086
10087
10088
10089
B0
B10
B20
B30
B40
B50
B60
B70
B80
B90
B100
PM tables
quadratic
linear
EN14214



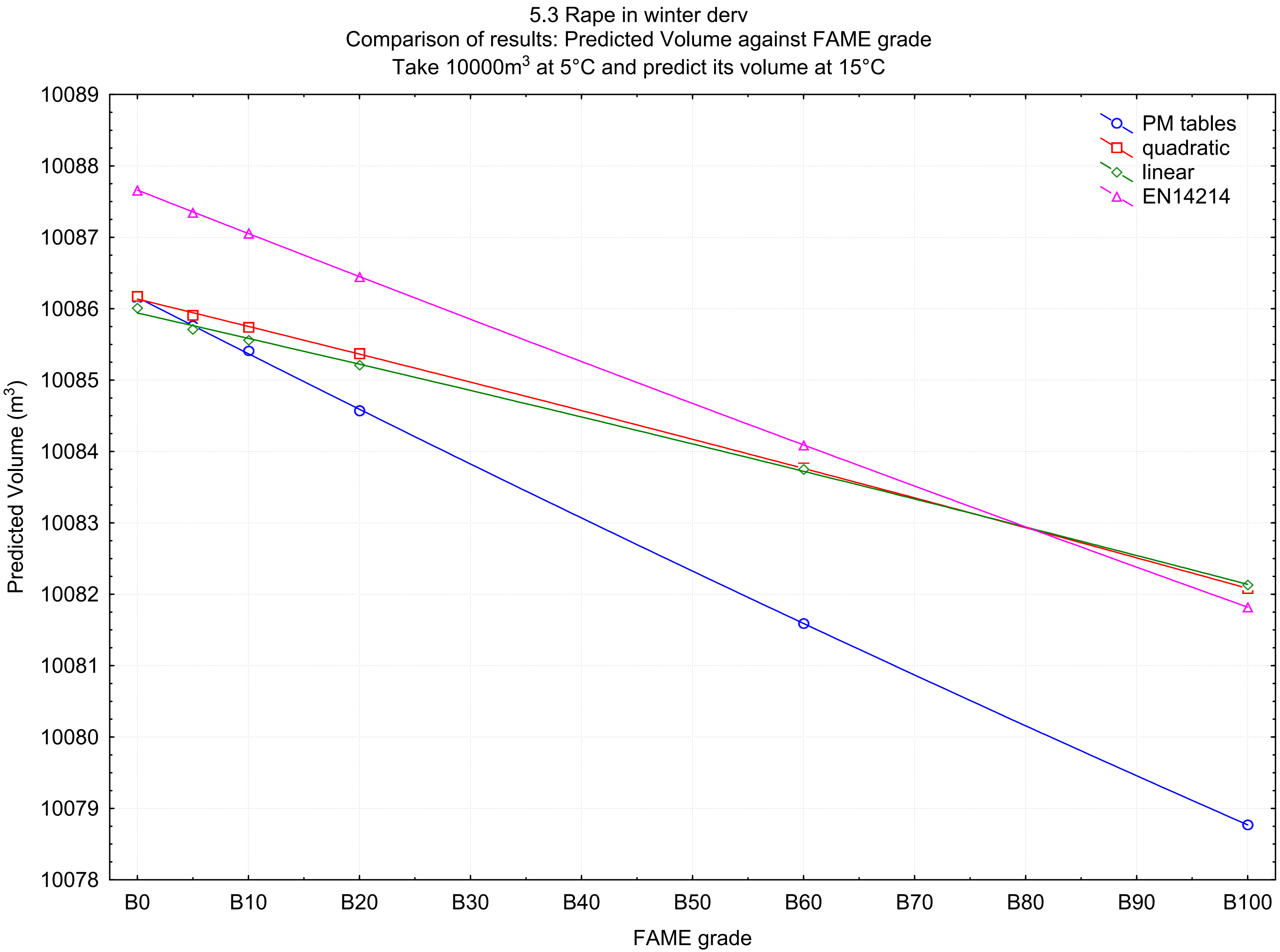
5.3 Soya in winter derv
Comparison of results: Predicted Volume against FAME grade
Take 10000m3 at 5°C and predict its volume at 15°C
Predicted Volume (m3)
10089
10088
10087
10086
10085
10084
10083
10082
10081
10080
10079
10078
B0
B10
B20
B30
B40
B50
B60
B70
B80
B90
B100
FAME grade
PM tables
quadratic
linear
EN14214


5.3 Palm in summer derv
Comparison of results: Predicted Volume against FAME grade
Take 10000m3 at 5°C and predict its volume at 15°C
Predicted Volume (m3)
10089
10088
10087
10086
10085
10084
10083
10082
10081
10080
10079
10078
B0
B10
B20
B30
B40
B50
B60
B70
B80
B90
B100
FAME grade
PM tables
quadratic
linear
EN14214


5.3 Palm in winter derv
Comparison of results: Predicted Volume against FAME grade
Take 10000m3 at 5°C and predict its volume at 15°C
Predicted Volume (m3)
10089
10088
10087
10086
10085
10084
10083
10082
10081
10080
10079
10078
B0
B10
B20
B30
B40
B50
B60
B70
B80
B90
B100
FAME grade
PM tables
quadratic
linear
EN14214



5.3 Rape in summer derv
Comparison of results: Predicted Volume against FAME grade
Take 10000m3 at 5°C and predict its volume at 15°C
Predicted Volume (m3)
10089
10088
10087
10086
10085
10084
10083
10082
10081
10080
10079
10078
B0
B10
B20
B30
B40
B50
B60
B70
B80
B90
B100
FAME grade
PM tables
quadratic
linear
EN14214


5.3 Rape in winter derv
Comparison of results: Predicted Volume against FAME grade
Take 10000m3 at 5°C and predict its volume at 15°C
Predicted Volume (m3)
10089
10088
10087
10086
10085
10084
10083
10082
10081
10080
10079
10078
B0
B10
B20
B30
B40
B50
B60
B70
B80
B90
B100
FAME grade
PM tables
quadratic
linear
EN14214

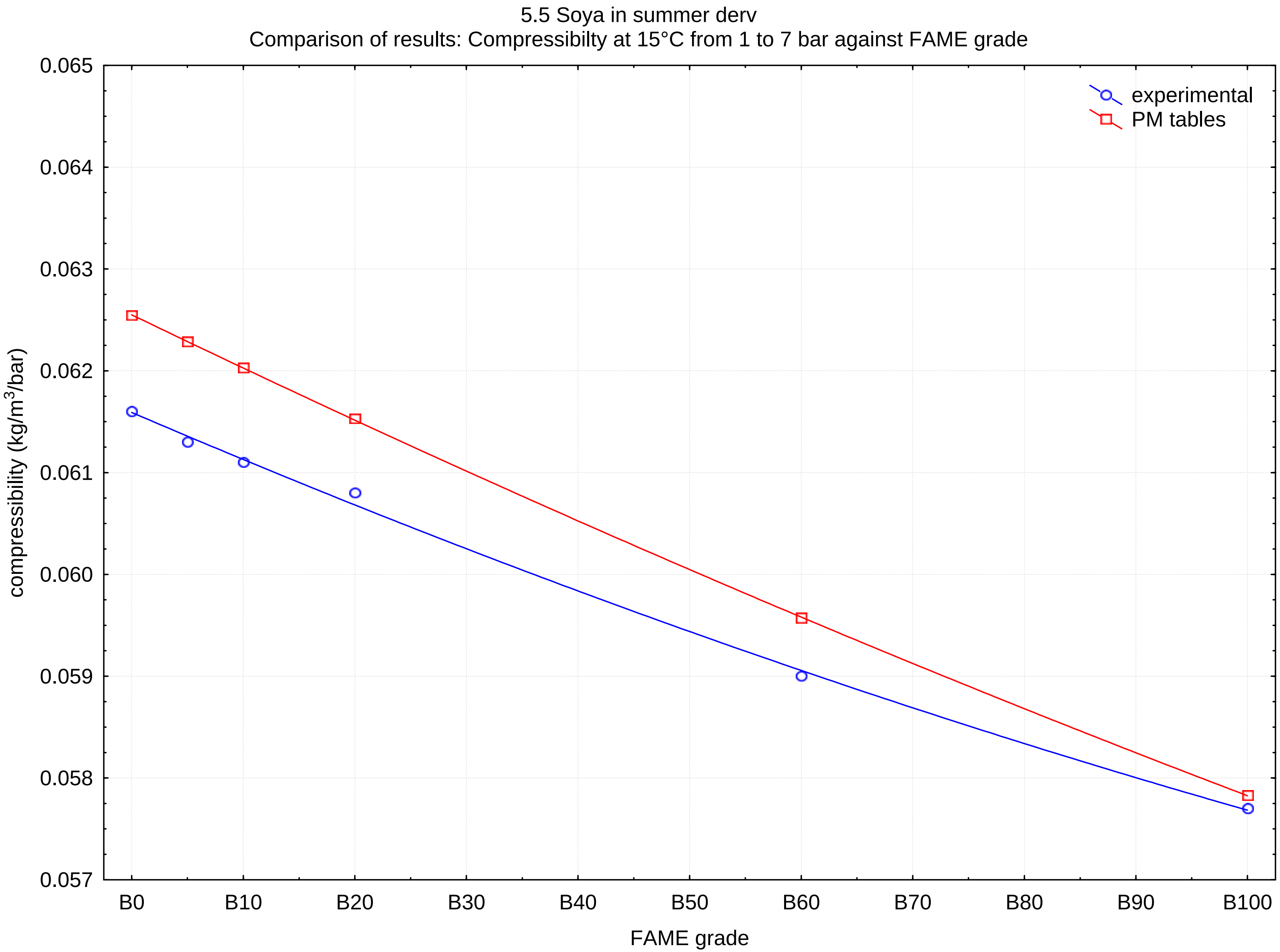
Take 10000 m^3 at 25°C and predict its volume at 15°C						
5.4	experimental density 25°C	PM Tables density 15°C	Volume predicted by PM Tables	Volume predicted from lab data quadratic fit	Volume predicted from lab data linear fit	Volume predicted using EN14214
Soya in Summer derv						
B100	878.36	885.35	9921.05	9917.73	9917.78	9918.36
B60	860.20	867.23	9918.99	9917.09	9917.08	9916.65
B20	842.25	849.33	9916.65	9916.55	9916.47	9914.89
B10	837.97	845.06	9916.08	9916.48	9916.38	9914.46
B5	835.80	842.90	9915.85	9916.43	9916.31	9914.24
B0	833.66	840.76	9915.49	9916.36	9916.25	9914.02
Soya in winter derv						
B100	878.36	885.35	9921.05	9917.73	9917.78	9918.36
B60	853.66	860.71	9918.11	9916.07	9916.05	9916.02
B20	829.39	836.50	9914.93	9914.45	9914.31	9913.58
B10	823.54	830.67	9914.13	9914.04	9913.88	9912.97
B5	820.66	827.80	9913.78	9913.87	9913.65	9912.67
B0	817.80	824.95	9913.39	9913.61	9913.46	9912.37
Palm in summer derv						
B100	868.49	875.50	9919.88	9916.33	9916.45	9917.44
B60	854.40	861.45	9918.12	9916.27	9916.25	9916.09
B20	840.55	847.64	9916.44	9916.35	9916.26	9914.72
B10	837.15	844.24	9916.07	9916.33	9916.24	9914.38
B5	835.45	842.55	9915.80	9916.36	9916.24	9914.20
B0	833.66	840.76	9915.49	9916.36	9916.25	9914.02
Palm in winter derv						
B100	868.49	875.50	9919.88	9916.33	9916.45	9917.44
B60	847.91	854.98	9917.32	9915.24	9915.22	9915.45
B20	829.05	836.17	9914.79	9914.58	9914.24	9913.55
B10	822.73	829.86	9914.02	9913.96	9913.77	9912.89
B5	820.24	827.38	9913.65	9913.80	9913.61	9912.62
B0	817.80	824.95	9913.39	9913.61	9913.46	9912.37

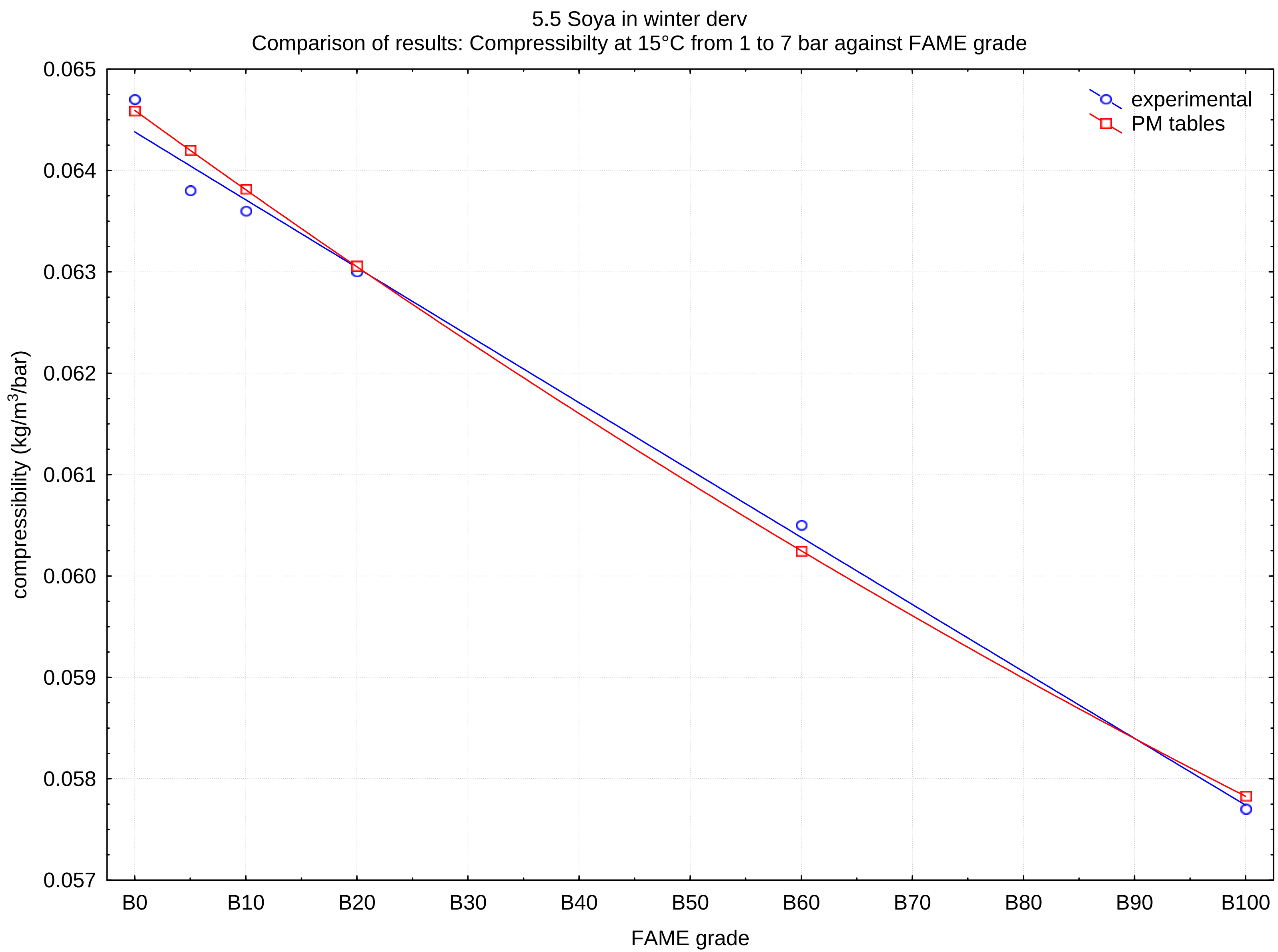
Take 10000 m³ at 25°C and predict its volume at 15°C						
5.4	experimental density 25°C	PM Tables density 15°C	Volume predicted by PM Tables	Volume predicted from lab data quadratic fit	Volume predicted from lab data linear fit	Volume predicted using EN14214
Rape in summer derv						
B100	876.33	883.32	9920.82	9917.97	9918.01	9918.17
B60	859.02	866.06	9918.79	9917.24	9917.23	9916.54
B20	841.92	849.00	9916.56	9916.61	9916.54	9914.86
B10	837.79	844.88	9916.01	9916.46	9916.36	9914.44
B5	835.80	842.90	9915.78	9916.39	9916.29	9914.24
B0	833.66	840.76	9915.49	9916.36	9916.25	9914.02
Rape in winter derv						
B100	876.33	883.32	9920.82	9917.97	9918.01	9918.17
B60	852.63	859.68	9917.96	9916.21	9916.19	9915.92
B20	829.22	836.34	9914.95	9914.48	9914.32	9913.56
B10	823.46	830.59	9914.15	9914.06	9913.88	9912.96
B5	820.66	827.80	9913.72	9913.87	9913.67	9912.67
B0	817.80	824.95	9913.39	9913.61	9913.46	9912.37
Coconut						
B100	866.44	873.46	9919.69	9911.14	9911.10	9917.25
Tallow						
B100	868.57	875.58	9919.90	9916.63	9916.78	9917.45

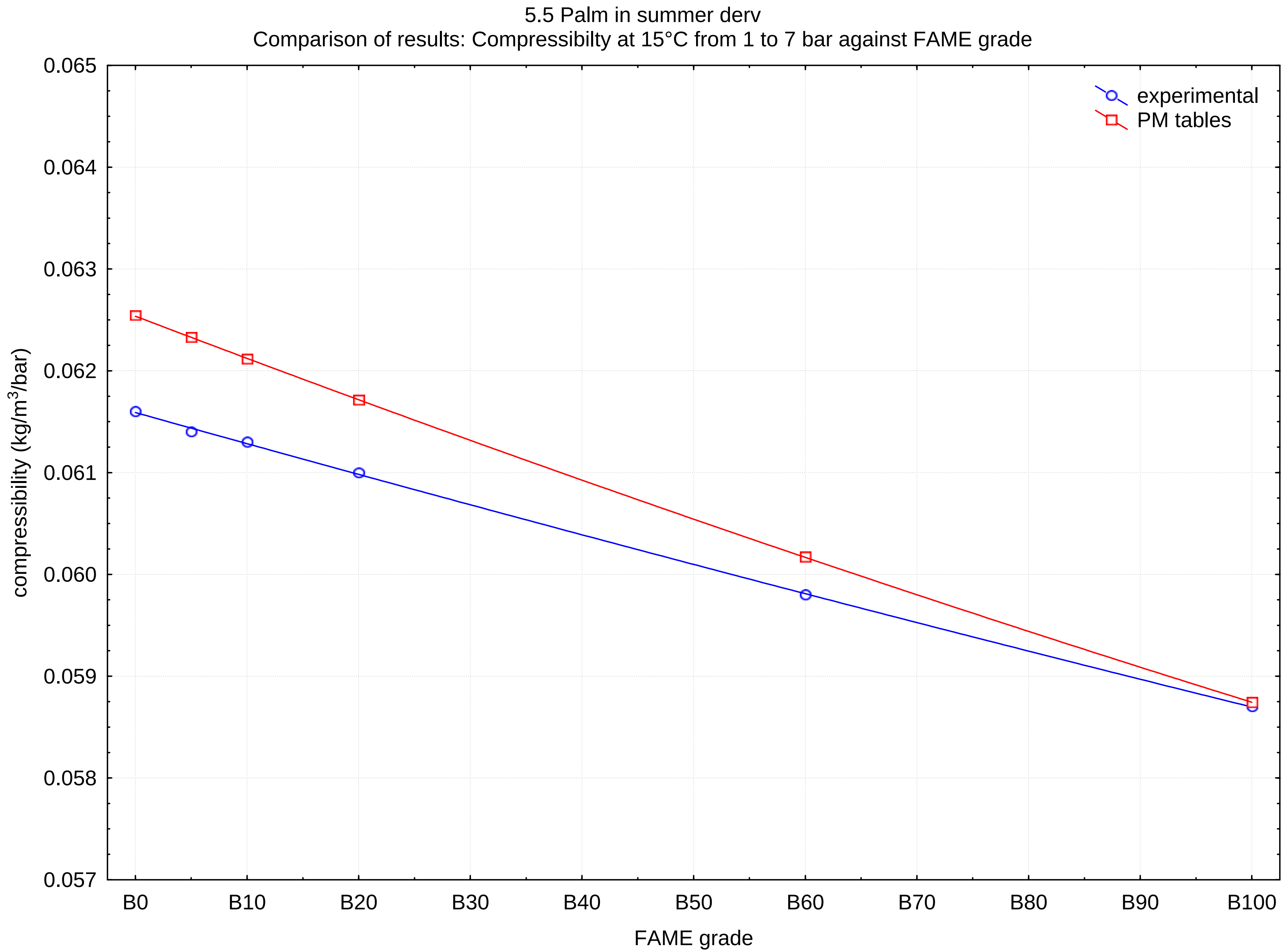
5.5 compressibility kg/m³/bar at 15°C 1 to 7 bar	
Soya in Summer derv	
B100	0.0577
B60	0.0590
B20	0.0608
B10	0.0611
B5	0.0613
B0	0.0616
Soya in winter derv	
B100	0.0577
B60	0.0605
B20	0.0630
B10	0.0636
B5	0.0638
B0	0.0647
Palm in summer derv	
B100	0.0587
B60	0.0598
B20	0.0610
B10	0.0613
B5	0.0614
B0	0.0616
Palm in winter derv	
B100	0.0587
B60	0.0610
B20	0.0644
B10	0.0638
B5	0.0641
B0	0.0647

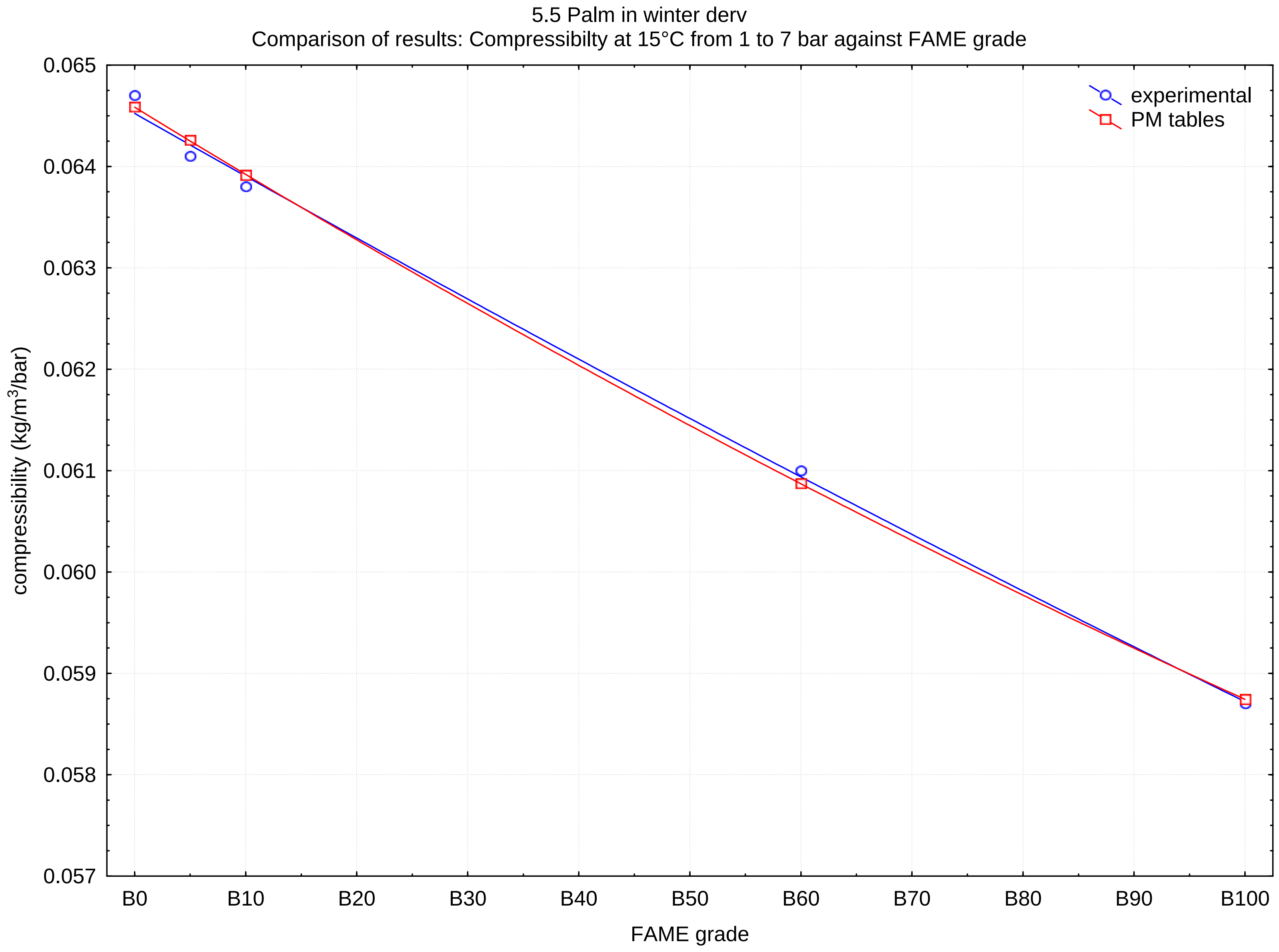
Rape in summer derv	
B100	0.0575
B60	0.0593
B20	0.0608
B10	0.0613
B5	0.0615
B0	0.0616
Rape in winter derv	
B100	0.0575
B60	0.0602
B20	0.0631
B10	0.0637
B5	0.0640
B0	0.0647
Coconut	
B100	0.0629
Tallow	
B100	0.0585

5.6 Linear expansivity coefficient	
Soya	-0.7275
Palm	-0.7319
Rape	-0.7241
Coconut	-0.7776
Tallow	-0.7291
EN14124	-0.723

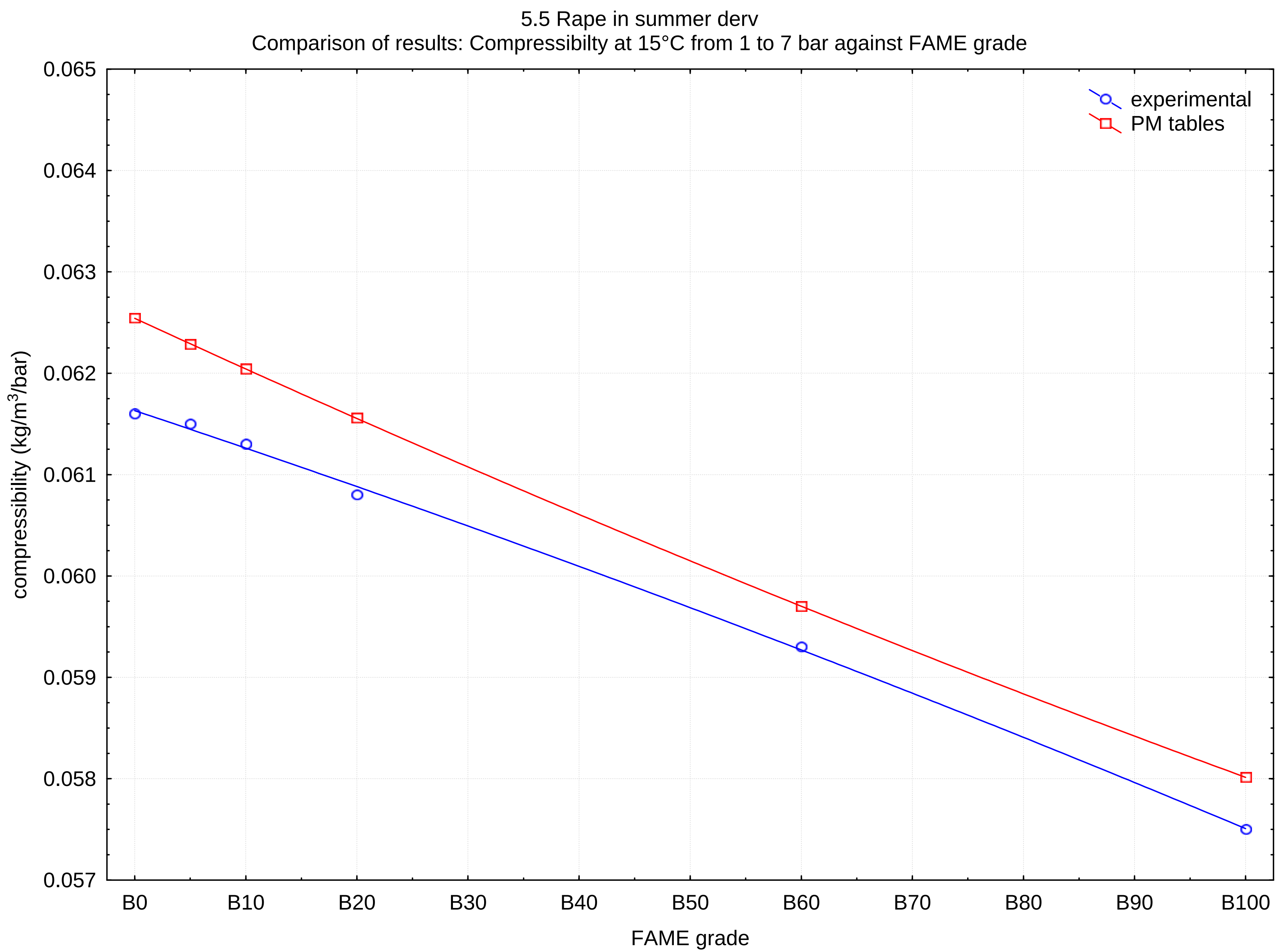

5.5 Soya in summer derv
Comparison of results: Compressibilty at 15°C from 1 to 7 bar against FAME grade
0.065
0.064
0.063
0.062
0.061
0.060
0.059
0.058
0.057
compressibility (kg/m3/bar)
experimental
PM tables
B0
B10
B20
B30
B40
B50
B60
B70
B80
B90
B100
FAME grade


5.5 Soya in winter derv
Comparison of results: Compressibilty at 15°C from 1 to 7 bar against FAME grade
0.065
0.064
0.063
0.062
0.061
0.060
0.059
0.058
0.057
compressibility (kg/m3/bar)
B0
B10
B20
B30
B40
B50
B60
B70
B80
B90
B100
FAME grade
experimental
PM tables

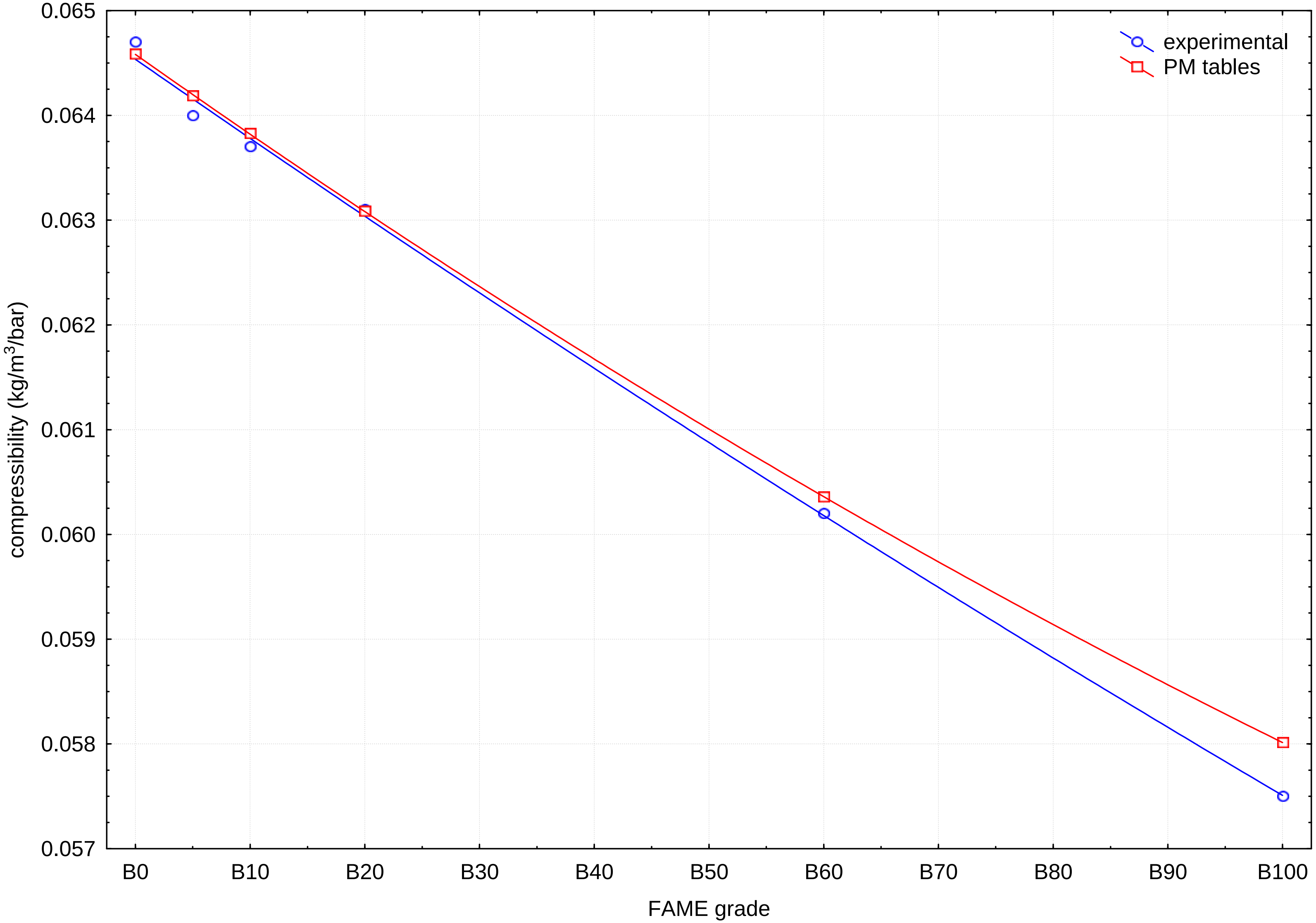

5.5 Palm in summer derv
Comparison of results: Compressibilty at 15°C from 1 to 7 bar against FAME grade
compressibility (kg/m3/bar)
0.065
0.064
0.063
0.062
0.061
0.060
0.059
0.058
0.057
B0
B10
B20
B30
B40
B50
B60
B70
B80
B90
B100
FAME grade
experimental
PM tables



5.5 Palm in winter derv
Comparison of results: Compressibilty at 15°C from 1 to 7 bar against FAME grade
0.065
0.064
0.063
0.062
0.061
0.060
0.059
0.058
0.057
compressibility (kg/m3/bar)
B0
B10
B20
B30
B40
B50
B60
B70
B80
B90
B100
FAME grade
experimental
PM tables


5.5 Rape in summer derv
Comparison of results: Compressibilty at 15°C from 1 to 7 bar against FAME grade
experimental
PM tables
0.065
0.064
0.063
0.062
0.061
0.060
0.059
0.058
0.057
compressibility (kg/m³/bar)
B0
B10
B20
B30
B40
B50
B60
B70
B80
B90
B100
FAME grade

5.5 Rape in winter derv
Comparison of results: Compressibilty at 15°C from 1 to 7 bar against FAME grade



6 Conclusions

6.1 The expansivities of pure FAMEs were found to be reasonably linear, and comply sufficiently well with the ISO EN14214 factor of 0.723 for this correction to be retained.

6.2 While FAMEs such as soya, rape, and palm are being produced in large quantities with the manufacture closely monitored, it must be remembered that even slight changes to the feed stock or chemical process can produce a substantial change in the quality of product. The testing carried out here has been only with one set of samples, so some variation may be seen with FAME from other sources. This is particularly so with tallow where the raw material is by no means consistent.

6.3 Coconut has been seen to behave in a somewhat non-standard fashion, and this is a good example of how a different chemical composition can cause substantial variation in the results. A shorter carbon chain length and different level of saturation is evident in this case.

6.4 A 10˚C temperature change was used to compare the effect of applying corrections either from the PM tables or the EN14214 factor. As should be the case the tables predicted the expansion of mineral diesels within 0.01%. However for pure FAMEs the tables would give errors of the order of 0.04%.
Use of the EN14214 factor would reduce this to within 0.01%.

6.5 The observed compressibility of pure tallow, palm and soya FAME and pure winter derv were accurately predicted by the PM Tables with differences between -0.0002 and 0.0001. However, pure summer derv was less accurately prediced with a difference of 0.0009. As a consequence, the summer derv blends with soya, palm and rape FAME were also less accurately predicted by the PM Tables with, on average, differences of 0.0006 and 0.0007.

In general, the PM Tables predict the compressibility of FAMEs satisfactorily. This can be shown by carrying out a volume calculation. Consider a true volume of 10,000.000m^3 of three pure FAMEs at 15°C & 1bar with assumed densities as tabulated in Table 6.5.

6.5 Comparison of calculated volumes using PM Table compressibilities and experimental compressibilities				
FAME	Assumed Density at 15°C & 1bar	PM Table Volume at 15°C & 7bar	Experimental Volume at 15°C & 7bar	Volume Difference
-	kg/m^3	m^3	m^3	m^3
soya	885.65	9,996.084	9,996.093	0.008
rape	883.58	9,996.062	9,996.097	0.035
coconut	874.21	9,995.960	9,995.685	-0.275

The differences between the PM Table and experimental calculated volumes are relatively small.